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## CONSUMPTIVE USE OF WATER BY FOREST AND RANGE VEGETATION

By L. R. Rich

IRRIGATION DIVISION

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AMERICAN SOCIETY OF CIVIL ENGINEERS

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PAPERS

# CONSUMPTIVE USE OF WATER BY FOREST AND RANGE VEGETATION

By L. R. Rich[1]

Synopsis

Consumptive use of water by forest and range vegetation is important to the irrigation economy of the West, because the water available for irrigation is the residual precipitation or that left over after watershed requirements have been met. Consumptive use of water by forest and range vegetation depends on the distribution and occurrence of precipitation, the amount of water held by the soil, and the character and type of the vegetation.

Under natural rainfall conditions, consumptive use of water can be determined by dividing the year into four periods: (1) Soil moisture recharge; (2) water surplus; (3) soil moisture utilization; and (4) water deficit. Each period must be considered separately. Measured field data are presented to show the workability of this method. Data are also presented that show the consumptive use of vegetation grown under natural rainfall conditions in open-top metal containers at El. 2600 and El. 5100. Consumptive-use data obtained from watersheds varying from desert grassland-chaparral vegetation at El. 3800 (16.22 in. precipitation) to pine-fir forest vegetation from El. 6500 to El. 8000 (34.19 in. precipitation) have followed a similar pattern.

Data from measured areas have shown small differences in consumptive use between those kept bare of vegetation and those in various types of vegetation, and no significant differences in consumptive use between a watershed in good and poor grass cover. The major problem is not whether watersheds kept bare of vegetation would yield most water, but to determine the type of vegetation that interferes least with water yield and still controls erosion and sediment. In the Southwest, grasses appear to interfere least with water yields, while half-shrubs, winter annuals, and evergreen shrubs (all characteristic of deteriorated vegetation) tend to reduce water yields.

Note.—Written comments are invited for publication; the last discussion should be submitted by April 1, 1952.

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## Introduction

Consumptive use of water by forest and range vegetation is important to the irrigation economy of the West. The water available as stream flow for irrigated and riparian areas is the residual precipitation, or that remaining after watershed requirements have been met. As existing streams approach full development and increasing populations demand more and more water, the major hope for maintaining and increasing water supplies lies in better management and use of watersheds.

## Conditions That Influence Consumptive Use

In contrast to irrigated areas and other areas that receive unlimited or supplemental water, the only water available to forest and range vegetation on the watersheds is the natural precipitation. Consumptive use is therefore limited by the amount and distribution of precipitation and the moisture held in the soil after periods of abundant precipitation. An unlimited water supply is seldom available to forest and range vegetation during the entire year. The exceptions to this condition may be riparian vegetation along perennial streams and wet meadows, or other limited areas at higher elevations, such as some areas in eastern New Mexico, where precipitation is high, where evapo-transpiration losses are low, and where rainfall distribution approaches potential evapo-transpiration. The wide variations in the consumptive-use data at hand show the need for consideration of climatic and watershed conditions as well as type of vegetation.

*Distribution of Precipitation.*—Climatic variations influence consumptive use of watershed vegetation. Winter precipitation decreases rather uniformly from almost 100% of the yearly total on the Pacific Coast to less than 20% in eastern New Mexico. In the northern part of the United States winter precipitation occurs as snow, whereas in the Southwest it is a combination of rain and snow, depending on winter temperatures that may vary widely from year to year.

At a particular location there are variations in both the amount and the distribution of annual precipitation that affect consumptive use and require data from long periods of measurement to determine averages. In the Southwest particularly, hydrologic data and the complex relationship between climate and the physical environment unfold slowly because of the low precipitation, infrequent periods of heavy precipitation, long and frequent droughts, and wide variations in these factors from year to year. There is danger in using averages in any study relating to water use, water yields, and climate. For example, during the 15-yr period of record at the large undisturbed-soil lysimeters on the Sierra Ancha Experimental Forest, Tonto National Forest, in central Arizona, the highest consumptive use and more than half of the total water yield were recorded in one winter (1940–41). On the other hand, the highest summer consumptive use and more than half of the total summer water yield resulted from one storm (September 17 to 19, 1946).

*Amount of Precipitation.*—Consumptive use does not vary directly with annual precipitation. An area seldom uses all the rainfall that falls on it, and there is some stream flow even in the driest years. Increasingly higher

consumptive use and stream flow take place during wet years. This is exemplified by rainfall, runoff, and consumptive-use data from three watersheds at Sierra Ancha Experimental Forest, plotted in Fig. 1. Consumptive use accounts for most of the first 10 in. to 15 in. of precipitation, leaving only a

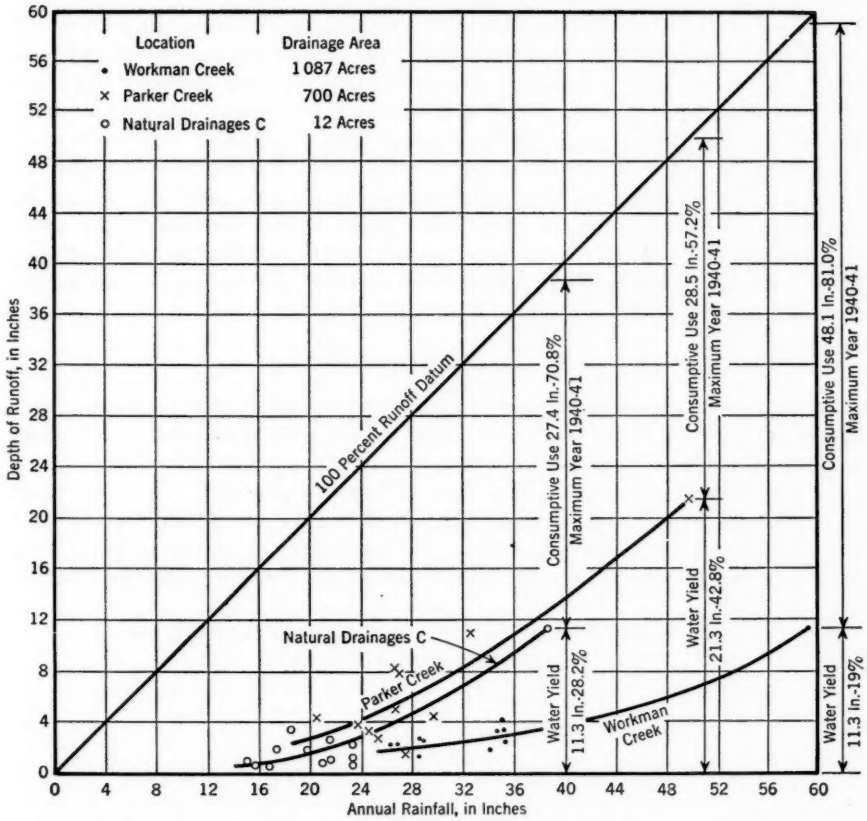


FIG. 1.—CONSUMPTIVE USE AND WATER YIELDS FOR SIERRA ANCHA, ARIZONA, WATERSHEDS

relatively small amount available for stream flow. With higher precipitation, there is an increasingly lower percentage of consumptive use and a resulting higher water yield.

Potential consumptive use (the amount of water an area would use if an adequate supply were available during the entire year) was not satisfied even in 1940–41 (the wettest year since 1905) when precipitation was over 200% of average. During the period of record there has not been a year of sufficiently high annual rainfall to locate the point where the yield line parallels the 100% datum line in Fig. 1. This is the point at which the consumptive use becomes constant and the difference is yielded as stream flow. Consumptive use has been 27 in. on Natural Drainages (El. 4555 to El. 4900), 28 in. on Parker Creek (El. 5500 to El. 7300), and 48 in. on Workman Creek (El. 6500 to El. 8000),

all in central Arizona. All these totals are higher than average annual rainfall, thus pointing out the limitations of averages.

*Variations in Watershed Conditions.*—Watershed conditions that influence consumptive use are also subject to wide variation. The term watershed condition as used in this paper refers to topography, depth of soil, vegetation, and slope of the area. Some watersheds are flat, with deep soils that retain water from periods of excess precipitation for use during periods of deficient precipitation. Other watersheds are steep, the soils are shallow, there are large areas of exposed bedrock, the drain-out is rapid, and comparatively little moisture is held in the soil. Different types and densities of vegetation grow on watersheds, and the use of moisture varies with the species of plants and their relative abundance. For example, winter annuals grow and use water during the winter, evergreen shrubs use some water throughout the year, but water use by grasses is largely limited to the summer growing season. With different densities of vegetation there are different ratios of transpiration from plants and evaporation from bare soil.

## Potential Consumptive Use

Many studies have been made of water use by cultivated crops and associated native vegetation[2,3,4] and by trees.[5,6] The results all confirm the great amount of water required to produce one unit of dry vegetation matter.

Actual consumptive use is less than potential consumptive use over most forest and range watersheds in the Southwest because of deficient rainfall and rainfall distribution that differs from use requirements of the plants. This difference can be shown by a comparison of annual rainfall with transpiration

TABLE 1.—Water Use in Inches By Plants With Unlimited Water Supply

| Item | Period | | | | | Total for year |
|---|---|---|---|---|---|---|
| | November–March | April–May | June | July–September | October | |
| Precipitation, inches... | 17.55 | 1.00 | 0.11 | 7.55 | 0.59 | 26.80 |
| Evaporation, inches... | 13.46 | 18.03 | 10.94 | 25.80 | 5.68 | 73.91 |
| Use by shrubs, inches.. | 4.85 | 10.28 | 8.54 | 24.76 | 5.46 | 53.89 |

losses from plants with an unlimited water supply. To determine transpiration losses at Sierra Ancha (El. 5100) with an unlimited water supply, three evergreen chaparral species, point-leaf manzanita (*Arctostaphylos pungens*), shrub live oak (*Quercus turbinella*), and desert ceanothus (*Ceanothus greggi*) were

[2] "The Water Requirement of Plants. II," by L. J. Briggs and H. L. Shantz, *Bulletin No. 285*, Bureau of Plant Industry, U. S. Dept. of Agriculture, 1913.

[3] "Relative Water Requirement of Plants," by Lyman J. Briggs and H. L. Shantz, *Journal of Agricultural Research*, U. S. Dept. of Agriculture, Vol. 3, 1914, pp. 1–64.

[4] "The Water Requirement of Plants at Akron, Colo.," by H. L. Shantz and Lydia N. Piemeisel, *Journal of Agricultural Research*, U. S. Dept. of Agriculture, Vol. 34, 1927, pp. 1093–1190.

[5] "Water Utilization by Trees, with Special Reference to the Economic Forest Species of the North Temperate Zone," by Oran Raber, *Miscellaneous Publication No. 257*, U. S. Dept. of Agriculture, 1937.

[6] "Transpiration by Forest Trees," by Robert E. Horton, *Monthly Weather Review*, U. S. Weather Bureau, Vol. 51, 1923, pp. 571–581.

grown in sealed-top metal containers. Water was added at weekly or biweekly intervals to maintain the supply at optimum field-moisture capacity. The results are summarized in Table 1, and monthly use figures with average precipitation for the area are shown in Fig. 2.

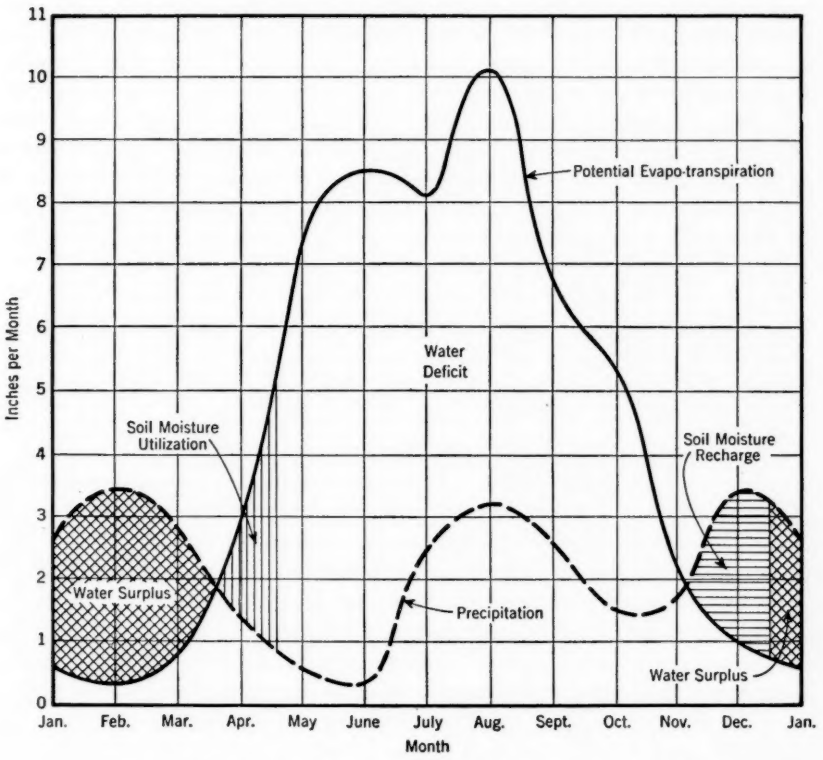


FIG. 2.—WATER USE AND WATER SURPLUS PERIODS FOR SIERRA ANCHA EXPERIMENTAL FOREST, ARIZONA

Precipitation for the year of measurements totaled 26.80 in., and evaporation for the same period was 73.91 in., as measured by a United States Weather Bureau evaporimeter. The average consumptive use of 53.89 in. was almost double the precipitation. It amounted to nearly 73% of the evaporation. Results of this study show that enormous quantities of water will be transpired by plants in the chaparral zone when unlimited supplies are made available.

These data may be applicable to riparian vegetation along perennial streams that have unlimited amounts of water available for use. However, except for relative comparisons, these data point out the limitations of sealed-top containers in studying consumptive use of native vegetation on the well-drained slopes that make up the greater portion of watershed areas in the West.

## Actual Consumptive Use

Transpiration, unless the attendant soil evaporation is considered, is of very little use in determining consumptive use.[7] A. F. Meyer[8] has developed curves for evaporation from land areas and also for transpiration. These curves are based on temperature and monthly rainfall for evaporation and temperature for transpiration. Mr. Meyer points out, however, that availability of water can be a factor in both evaporation and transpiration. Evaporation from soil areas[9] is usually less than from a free water surface, and the difference in the quantity of evaporation increases as the soil becomes drier. Vegetation, in that it decreases wind velocity, also decreases evaporation. Transpiration is independent of the soil moisture content as long as the latter is above the wilting points of the vegetation. If rainless periods during the growing season are sufficiently prolonged, available moisture may be used by evapo-transpiration regardless of the size, kind, or density of the vegetation.

## Method of Determining Consumptive Use

Since forest and range vegetation does not have an unlimited water supply, a method[10] that appears suited to determining consumptive use under natural conditions consists of dividing the year into four periods and then considering the amount of water available and the amount used during each period. These periods are: (*a*) Soil moisture recharge; (*b*) water surplus; (*c*) soil moisture utilization; and (*d*) water deficit. A generalized graph showing these periods is given in Fig. 2. The cycle starts at the point where the potential evapotranspiration curve crosses the precipitation curve (in the fall of the year) and becomes less than the rainfall. For a period that depends on both the amount of precipitation and depth and storage capacity of the soil, the surplus precipitation is satisfying the soil moisture deficit. The second period begins when the soil moisture reaches field capacity and the surplus water is yielded as stream flow. The third period begins when the potential evapo-transpiration crosses the rainfall line and continues until the available soil moisture is used. The fourth period is the summer water-deficit period in which there is less water available than is needed for consumptive use.

Fig. 2 illustrates the influence of climatic and watershed conditions. The proportion of the rainfall diagram that falls under the potential use curve reflects the influence of climate. In general, when the precipitation pattern is similar to the use curve, consumptive use is highest. In winter, use is low, and high precipitation results in water available for stream flow. The influence of watershed conditions is reflected in the amount of water held in the soil during the period of soil moisture recharge. In general, deep soils on gently sloping watersheds hold more water than shallow soils on steep areas.

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[7] "Hydrology," *Physics of the Earth Series*, Vol. IX, ed. by Oscar E. Meinzer, McGraw-Hill Book Co., Inc., New York, N. Y., 1942, pp. 259–330.

[8] "The Elements of Hydrology," by Adolph F. Meyer, 2d Ed. Rev., John Wiley & Sons, Inc., New York, N. Y., 1928.

[9] "Forest Influences," by Joseph Kittredge, McGraw-Hill Book Co., Inc., New York, N. Y., 1948.

[10] "An Approach Toward a Rational Classification of Climate," by C. W. Thornthwaite, *The Geographical Review*, Vol. XXXVIII, 1948, pp. 55–94.

## Test of Method

Water-use data from plants grown in open-top metal containers and the water-yield data from large natural lysimeters were combined to test the workability of this method.

The water-use study in the chaparral zone was conducted in the Sierra Ancha Experimental Forest at El. 5100. Annual precipitation in this zone averages about 25 in., of which two thirds falls in the winter (October through May) and one third in the summer (June through September). Evaporation from a United States Weather Bureau evaporimeter was about 72 in. annually, and the soil was a residual silty clay loam derived from quartzite. Plants were transplanted in their original soil cores without disturbance to galvanized iron containers. The plants used were of about the same size and density as the plants under natural conditions. The open-top metal containers were buried in the ground so that approximately normal soil temperatures would prevail, and percolation water was drained at the bottom of the cans. Consumptive use was determined by weekly weighings. Containers of bare soil without plants served as checks for measurement of consumptive use (evaporation) by bare soil. During long dry periods it was necessary to add water to keep the plants functioning normally in their confined space, where they could not draw on moisture from deeper soil layers. The data derived from this test are shown in Fig. 3 and Table 2. Consumptive use varied during the year. Summer use depended on the amount of water available through rainfall, and winter use depended on growing conditions. Evaporation was the factor that most nearly described use conditions during the winter period. Estimat-

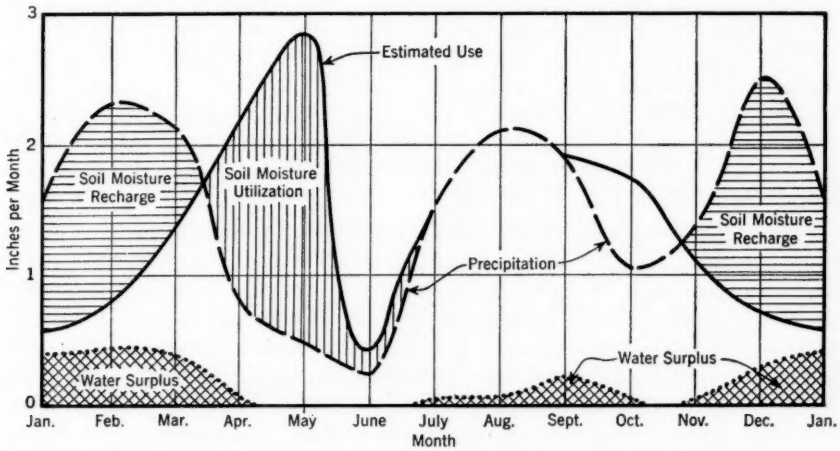


Fig. 3.—Consumptive Use and Water Yield from an Untreated Natural Lysimeter at Sierra Ancha Forest, Arizona

ing equations were developed from the actual amounts of water used by plants by relating the summer use to rainfall and by relating the winter use to evaporation. Other variables, such as temperature, humidity, and wind movement, were added to the estimating equations without serving any appreciable

improvement in accuracy. Using average monthly rainfall for the summer period and evaporation for the winter period, the estimated use was derived from these equations and is shown in Col. 4, Table 2.

Water-yield data (Cols. 6 and 7, Table 2) are from the untreated Base Rock lysimeter located at Sierra Ancha Experimental Forest. This lysimeter

TABLE 2.—ESTIMATED DISTRIBUTION OF PRECIPITATION AS DETERMINED BY THE UNTREATED BASE ROCK LYSIMETER AT SIERRA ANCHA EXPERIMENTAL FOREST, ARIZONA, 1935–1948 (IN INCHES)

| Month | Average precipitation | Evaporation | Estimated use | Surplus | Runoff | | Accumulated surplus | Consumptive Use | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Surface | Subsurface[a] | | Actual | Potential[b] |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| (a) WINTER PERIOD | | | | | | | | | |
| October | 1.04 | 5.54 | 1.77 | 0 | 0.01 | 0 | 0 | 1.03 | 5.46 |
| November | 1.38 | 3.33 | 1.04 | 0.34 | 0.03 | 0 | 0.31 | 1.04 | 2.27 |
| December | 2.50 | 2.21 | 0.67 | 1.83 | 0.01 | 0.25 | 1.88 | 0.67 | 0.80 |
| January | 1.58 | 1.89 | 0.57 | 1.01 | 0 | 0.39 | 2.50 | 0.57 | 0.62 |
| February | 2.30 | 2.45 | 0.75 | 1.55 | 0.01 | 0.42 | 3.62 | 0.75 | 0.32 |
| March | 2.13 | 4.33 | 1.37 | 0.76 | 0.01 | 0.37 | 4.00 | 1.37 | 0.84 |
| April | 0.76 | 6.71 | 2.15 | 0 | 0 | 0.01 | 2.60 | 2.15 | 2.80 |
| May | 0.50 | 8.99 | 2.90 | 0 | 0.01 | 0 | 0.19 | 2.90 | 7.48 |
| Subtotal | 12.19 | 35.45 | 11.22 | 5.49 | 0.08 | 1.44 | .... | 10.48 | 20.59 |
| (b) SUMMER PERIOD | | | | | | | | | |
| June | 0.24 | 10.64 | 0.40 | 0 | 0 | 0 | 0 | 0.40 | 8.54 |
| July | 1.45 | 10.27 | 1.50 | 0 | 0.03 | 0 | 0 | 1.45 | 7.98 |
| August | 2.11 | 8.61 | 2.05 | 0 | 0.03 | 0.01 | 0 | 2.07 | 10.06 |
| September | 1.93 | 7.64 | 1.90 | 0 | 0.06 | 0.14 | 0 | 1.73 | 6.72 |
| Subtotal | 5.73 | 37.16 | 5.85 | 0 | 0.12 | 0.15 | .... | 5.65 | 33.30 |
| Annual Total | 17.92 | 72.61 | 17.07 | 5.49 | 0.20 | 1.59 | .... | 16.13 | 53.89 |

[a] Percolation yield. [b] Determined from sealed-top cans.

is unique in that an undisturbed block of soil 18 ft by 50 ft and from 3 to 6 ft deep, overlying impervious quartzite bedrock, is used for measurements of rates and quantities of surface and subsurface runoff. The soils fall within the reddish chestnut soil grouping. Except for the surface soil, the profile shows no lines of demarcation or leaching between soil horizons. The entire profile contains partially disintegrated quartzite rock fragments from which the soils were derived, is noncalcareous, has a pH of about 6.3, and contains a high percentage of fine silt and clay in the subsoil. Vegetation cover is composed of the species characteristic of the semidesert grassland. The present ocular density is about 30%. The elevation of the test site is 4,500 ft.

Annual precipitation at the Base Rock lysimeters has averaged 17.92 in. (12.19 in. during the winter and 5.73 in. in summer). Evaporation, as determined by a United States Weather Bureau evaporimeter, was 72.61 in. annually, and the water yield has averaged 1.79 in. or 10% of the precipitation. The water yield was distributed 89% in winter and 11% in summer. Nearly

91% of the winter yield and 56% of the summer yield has occurred as subsurface flow. Consumptive use (Col. 9, Table 2) has averaged 16.13 in. annually or 90% of the precipitation (10.48 in. of the winter precipitation and 5.65 in. of the summer moisture). The estimated use (Col. 4) is 17.07 in. or 0.94 in. higher than actual use. In this tabulation, October was considered a winter month, and the water use was dependent on growing conditions. Average rainfall is less than estimated use for the first part of the month, and 0.74 in. of the deficit is incurred in the first part of October, before the precipitation exceeds the consumptive use. The remaining 0.20 in. is the surface runoff that results from storm intensity and surface soil conditions rather than total water supply. The estimated potential consumptive use by vegetation grown in sealed-top containers is 53.89 in.

Potential consumptive use is much higher than precipitation; yet there is a period of surplus water available for stream flow. Between November and March precipitation is high, and evaporation from the soil and transpiration from plants are low. During this period precipitation exceeds consumptive use, the soil fills with water, and surplus water is yielded as stream flow. On the average, there is 9.9 in. of precipitation during the 5-month period, of which 4.4 in. goes to consumptive use (evapo-transpiration), 4.0 in. is held in the soil, and 1.5 in. is yielded as stream flow, mainly through percolation. This period is the only consistent water-yielding period.

The moisture held in the soil reservoir is used during the spring dry period. The effect of depth and type of soil on consumptive use is illustrated by the data in Table 2. A deeper soil or a soil with a higher moisture-holding capacity could easily retain, for use during the spring and early summer drought, the rainfall that was yielded as stream flow. A shallower soil or one with less total soil moisture-holding capacity should retain less water for use during the spring drought and allow a higher water yield. The water yield from summer precipitation was largely due to surface runoff from thunderstorms, when rainfall intensities exceeded the infiltration capacity of the soil, and also from a rare type late summer storm of large total quantity and long duration. One storm of this type (September 17 to 19, 1946) is included in the data shown in Table 2, and, therefore, summer water yields are higher than the average to be normally expected.

## Data on Consumptive Use

Consumptive-use data (the difference between precipitation and water yield) from the Sierra Ancha Experimental Forest are available from transpiration studies at El. 2500 and El. 5100 (Table 3), and from watersheds that are typical of the semidesert grassland, chaparral, ponderosa pine, and pine-fir forest vegetation types from El. 3800 to nearly El. 8000 (Table 4). Rainfall at these stations is greater than that at corresponding elevations in most of the arid regions of the West, and the concentration of precipitation in winter probably results in lower consumptive use and higher water yield. All watersheds studied except those at Summit, Ariz., are underlain by nearly level beds of impervious quartzite. Measuring weirs are tied into this bedrock, and since there is little, if any, water diverted to other watersheds or to deep

seepage, the runoff measured is virtually the total surface and subsurface yield. Summit watersheds are located in the granitic type soil, and measuring weirs are not tied into bedrock. The wide variations in consumptive use in different watersheds and between average and maximum and minimum years suggest that little credence should be given to figures on consumptive use by forest and range vegetation unless climatic and watershed conditions are duly considered. El. 2500 when there was 26.33 in. annual rainfall consumptive use was 89% of the rainfall as determined by cans of bare soil, 92% as determined by grasses and 98% of the rainfall as determined by winter annuals. In all cases, consumptive use in summer was 100% of the rainfall. At El. 5100, with 30.32 in. of precipitation annually, consumptive use values were 78% of the rainfall for bare soil, 81% for grasses, and 84% of the rainfall for shrubs. At Base Rock lysimeters, El. 4500, in semidesert grassland cover (annual rainfall of 17.92 in.), consumptive use averaged 90% of the rainfall, but varied from 74% in 1940–41 (26.7 in. of rainfall) to 94% of the rainfall in 1938–39 (11.07 in. of rainfall). The high consumptive use from bare soil is noteworthy. Relatively little additional water was used by vegetation.

Data from watersheds have followed a similar pattern. Consumptive use at Summit watersheds (El. 3800) with semidesert grassland-chaparral

TABLE 3.—TESTS OF WATER USE FROM OPEN-TOP METAL CONTAINERS, SIERRA ANCHA EXPERIMENTAL FOREST, ARIZONA

| Condition measured | Year | Winter | | | Summer | | | Total Year | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Rain (inches) | Consumptive use (inches) | Use percentage of rain | Rain (inches) | Consumptive use (inches) | Use percentage of rain | Rain (inches) | Consumptive use (inches) | Use percentage of rain |
| (a) Elevation 2,500 Feet | | | | | | | | | | |
| Bare soil | 1936 | 14.41 | 11.49 | 80 | 11.92 | 11.98 | 101 | 26.33 | 23.47 | 89 |
| Grasses | 1936 | 14.41 | 12.10 | 84 | 11.92 | 12.17 | 102 | 26.33 | 24.27 | 92 |
| Half-shrubs | 1936 | 14.41 | 13.40 | 93 | 11.92 | 11.96 | 100 | 26.33 | 25.36 | 96 |
| Shrubs | 1936 | 14.41 | 13.26 | 92 | 11.92 | 12.08 | 101 | 26.33 | 25.34 | 96 |
| Woody legumes | 1936 | 14.41 | 12.83 | 89 | 11.92 | 11.99 | 101 | 26.33 | 24.82 | 94 |
| Winter annuals | 1936 | 14.41 | 13.77 | 96 | 11.92 | 11.98 | 101 | 26.33 | 25.75 | 98 |
| (b) Elevation 5,100 Feet | | | | | | | | | | |
| Bare soil | 1936 | 18.16 | 9.36 | 52 | 12.16 | 11.13 | 92 | 30.32 | 20.49 | 68 |
| | 1938 | 14.18 | 8.63 | 61 | 7.96 | 10.36 | 130 | 22.14 | 18.99 | 86 |
| | 1939 | 17.36 | 12.55 | 72 | 10.84 | 9.93 | 92 | 28.20 | 22.48 | 80 |
| Grasses | 1936 | 18.16 | 12.79 | 70 | 12.16 | 11.50 | 95 | 30.32 | 24.29 | 80 |
| | 1938 | 14.18 | 10.58 | 75 | 7.96 | 7.88 | 99 | 22.14 | 18.46 | 83 |
| | 1939 | 17.36 | 13.98 | 81 | 10.84 | 9.42 | 87 | 28.20 | 23.40 | 83 |
| Shrubs | 1936 | 18.16 | 13.89 | 76 | 12.16 | 11.73 | 96 | 30.32 | 25.62 | 84 |
| | 1938 | 14.18 | 10.52 | 74 | 7.96 | 7.82 | 98 | 22.14 | 18.34 | 83 |
| | 1939 | 17.36 | 14.86 | 86 | 10.84 | 9.24 | 85 | 28.20 | 24.10 | 85 |

vegetation has averaged 96.8% of the rainfall for nine small watersheds, but varied from 94 to 98% on these adjacent watersheds. Precipitation for the period averaged 16.78 in. The four Natural Drainages are adjacent watersheds varying from 9 to 18 acres, with grassland-chaparral vegetation (El. 4500 to

El. 4900), and consumptive use has varied from 90% to 95% of the rainfall. The difference is probably related to soil type. The upper parts of all watersheds (varying from 26 to 55% of their area), are composed of diabase-derived soil, whereas the soil on the lower parts is derived from quartzite. The areas with

TABLE 4.—Consumptive Use of Water by Forest and Range Vegetation, Sierra Ancha Experimental Forest

| Item studied | Winter | | | Summer | | | Total Year | | |
|---|---|---|---|---|---|---|---|---|---|
| | Rain (inches) | Consumptive use (inches) | Use percentage of rain | Rain (inches) | Consumptive use (inches) | Use percentage of rain | Rain (inches) | Consumptive use (inches) | Use percentage of rain |
| (a) Summit Watersheds[a] | | | | | | | | | |
| Watershed Number 9 (low use) | 11.16 | 10.71 | 96 | 5.54 | 4.92 | 89 | 16.70 | 15.63 | 94 |
| Watershed Number 6 (high use) | 11.21 | 11.03 | 98 | 5.65 | 5.55 | 98 | 16.86 | 16.58 | 98 |
| (b) Base Rock[b] Lysimeter | | | | | | | | | |
| Average of 13 years | 12.19 | 10.48 | 86 | 5.73 | 5.65 | 99 | 17.92 | 16.13 | 90 |
| Maximum year 1940–41 | 29.68 | 20.64 | 70 | 5.67 | 5.63 | 99 | 35.35 | 26.27 | 74 |
| Minimum year 1938–39 | 7.92 | 7.19 | 91 | 3.88 | 3.88 | 100 | 11.80 | 11.07 | 94 |
| (c) Natural Drainage Watersheds[c] | | | | | | | | | |
| Watershed A (open range) | 14.37 | 12.82 | 89 | 7.49 | 7.27 | 97 | 21.86 | 20.09 | 92 |
| Watershed B (protected) | 14.37 | 13.40 | 93 | 7.49 | 7.33 | 98 | 21.86 | 20.73 | 95 |
| Watershed C (protected) | 14.87 | 12.88 | 87 | 7.07 | 6.87 | 97 | 21.94 | 19.75 | 90 |
| Watershed D (moderately grazed) | 14.87 | 12.82 | 86 | 7.07 | 6.88 | 97 | 21.94 | 19.71 | 90 |
| (d) Parker Creek Watershed[d] | | | | | | | | | |
| Average of 15 years | 18.69 | 12.55 | 67 | 9.36 | 9.09 | 97 | 28.05 | 21.64 | 77 |
| Maximum year 1940–41 | 43.03 | 21.89 | 51 | 6.78 | 6.63 | 98 | 49.81 | 28.52 | 57 |
| Minimum year 1947–48 | 12.37 | 10.68 | 86 | 4.90 | 4.90 | 100 | 17.27 | 15.58 | 90 |
| (e) Workman Creek Watershed[e] | | | | | | | | | |
| Average of 10 years | 23.47 | 20.40 | 87 | 10.72 | 10.37 | 97 | 34.19 | 30.77 | 90 |
| Maximum year 1940–41 | 52.01 | 41.32 | 79 | 7.41 | 6.79 | 92 | 59.42 | 48.11 | 81 |
| Minimum year 1947–48 | 15.78 | 14.69 | 93 | 9.13 | 8.97 | 98 | 24.91 | 23.66 | 95 |

[a] 0.80 and 1.05 acres of grassland-chaparral at El. 3800–3900. [b] Semidesert grassland at El. 4500. [c] 9 to 18 acres of mixed grassland-chapparral at El. 4500–4900. [d] 700 acres of ponderosa pine-chaparral at El. 5500–7300. [e] 1,087 acres of pine-fir forest at El. 6500–8000.

the highest percentage of diabase-derived soil showed the highest consumptive use, those with the largest areas of quartzite-derived soil the lowest.

Consumptive use on Parker Creek, a 700-acre watershed with ponderosa pine-chaparral vegetation (El. 5500 to El. 7300), has averaged 77% or 21.64 in. consumptive use from 28.05 in. precipitation. The consumptive use has

varied from 57% to 90% of the rainfall. The soils are shallow, and there are areas of exposed bedrock, the slopes are steep, and the drain-out of excess precipitation is rapid. Ninety-six per cent of the water yield occurs during the winter and results from winter precipitation. Workman Creek and Parker Creek also illustrate the wide variations between watersheds less than a mile apart. Consumptive use on Workman Creek, in pine-fir forest type vegetation (El. 6500 to El. 8000), has averaged 90% of the precipitation (30.77 in. consumptive use from 34.19 in. of precipitation) and has varied from 81% to 95%. The high use is probably caused by storage of relatively large amounts of water in the deep soils during the winter surplus period, and later used by evapotranspiration during drought periods.

### Effect of Grass Density

The importance of watershed and climatic factors is illustrated by preliminary results from a 12-acre watershed (Natural Drainage C) with semidesert grassland-chaparral vegetation. The area was fenced and livestock use eliminated in 1934. The terrain is steep, the drain-out of excess precipitation is rapid, and generally there is a period of no runoff between storms. Between 1934 and 1947 there were 163 rainfall-runoff periods varing in duration from a few hours to 6 months. A highly significant correlation exists between precipitation and runoff in the equation:

$$Y = 1242\,X^{1.83} \qquad (1)$$

in which $Y$ is the runoff in cubic feet, and $X$ is the rainfall in inches.

During the period from 1934 to 1947, vegetation density more than doubled (to 20% ocular density). If vegetation has a significant influence on runoff, the plotting of residuals from the above equation should show a definite trend through the years—upward if increased vegetation favored water yield and downward if vegetation favored consumptive use. However, the residuals by years show no trend. There is a scatter of points with approximately the same number above and below the curve for any one year, and consumptive use in this particular area appears to be independent of vegetation changes that range between about 10% and 20% ocular density. However, from the standpoint of usability of water and sediment content, there is a marked difference. As vegetation densities increase, both erosion and the amount of soil carried in streams decrease.

### Relation of Consumptive Use to Water Yield

Since the water available for consumptive use on irrigated areas is the residual precipitation from watersheds, some comment on the effect of vegetation on stream flow is in order. Data from studies at the Sierra Ancha Experimental Forest have shown small differences in consumptive use between areas kept bare of vegetation and areas grown in various types of vegetation, and no significant differences in consumptive use between a watershed with good and poor grass cover. Decreased use on bare watersheds is largely hypothetical since no watershed can be kept bare of all vegetation; some plants

will grow under extremely adverse conditions. If perennial grasses are depleted through abuse, inferior species such as annuals, weeds, and half-shrubs usually replace the original vegetation. If chaparral species are burned out, the sprouting varieties readily recover and may even increase.

From a water-yield standpoint, the major question is not whether watersheds bare of vegetation would yield most water, but the type of vegetation that interferes least with water yield and still controls sediment. In the Southwest, with very few exceptions, grasses are dormant and do not use water during the winter water-yielding period. Water use is largely confined to the summer period when there is no surplus water, and surface evaporation alone could consume all the precipitation. During the winter, high transpiration by half-shrubs, winter annuals, and evergreen shrubs, all characteristic of a deteriorated vegetation, tends to reduce water yield. Total annual use by grasses is slightly higher than evaporation from bare ground but lower than losses from a deteriorated vegetation. The benefit of well-developed and well-maintained plant cover in checking soil erosion and sedimentation of reservoirs outweighs by many times the value of the slight amount of water it uses.

## Summary

Consumptive use of water by forest and range vegetation depends primarily on climatic and watershed conditions and on water availability. There are few areas in the West in which unlimited water is available for full potential consumptive use. The ability of plants to grow and use water is greatest in summer and least in winter. Actual water use is dependent on growing conditions when moisture is available. The availability of moisture depends on the distribution of precipitation and the moisture held in the soil for use during drought periods. Water use in the semidesert grassland zone was 92% of the precipitation for perennial grasses, 98% for winter annuals, and 89% of the precipitation lost from bare soil by evaporation. Consumptive use of water in the chaparral zone was 81% of the precipitation for grasses, 84% of the precipitation for shrubs, and 78% of the precipitation lost from bare soil by evaporation. The use on watersheds in the mixed grassland-chaparral zone ranged from 90% to 95% of the precipitation on 4 adjacent watersheds, depending on soil type and depth of soil. Water use on forested watersheds has varied from 77% to 90% of the rainfall, depending on depth of soil and slope.

A method that appears suited to determining consumptive use of water by forest and range vegetation is to divide the water year into four periods: (1) Soil moisture recharge; (2) water surplus; (3) soil moisture utilization; and (4) water deficit; and to consider each period separately. Vegetation or evaporation from bare soil can always use more water than falls as precipitation during the summer period in the Southwest, and consumptive use is dependent on total precipitation less the small amount of surface runoff that results from summer thunderstorms. Part of this surface runoff is dissipated from dry stream channels by riparian vegetation and evaporation. Water use during the winter period depends on growing conditions. The water that is surplus first satisfies the soil-moisture deficit, and the balance is yielded as stream

flow. Water use during the spring and early summer depends on the precipitation and the amount of moisture held in the soil from winter precipitation. Thus, consumptive use by forest and range vegetation depends on the amount and distribution of the rainfall, the climate, topography, and the storage capacity of the soils of the watershed as well as on the type of vegetation and the degree to which the vegetation use overlaps with the period of water surplus. The principal way in which man can influence water yield is by sound management and use of vegetation cover, through proper livestock grazing and timber harvesting, so that consumptive use overlaps and interferes least with the water-yielding period.